Commonwealth of Virginia
Department of Environmental Quality

Virginia Mercury Study

Work Plan

April 6, 2007

07-023

Passion. Expertise. Results.

Commonwealth of Virginia Department of Environmental Quality

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1. Introduction

This work plan summarizes the objectives, scope, and schedule for the Virginia Mercury Study. It is intended to guide the performance and tracking of the technical tasks.

Background

Human exposure to mercury is most commonly associated with the consumption of contaminated fish. Due to measured high levels of mercury in fish, at least 44 U.S. states have, in recent years, issued fish consumption advisories. These advisories may suggest limits on the consumption of certain types of fish or they may recommend limiting or not eating fish from certain bodies of water because of unsafe levels of mercury contamination. States have identified more than 6,000 individual bodies of water as mercury impaired and have issued mercury fish advisories for more than 2,000 individual bodies of water.

Until 2002, significant mercury contamination in Virginia surface waters was known only in three rivers (the North Fork of the Holston River, the South River, and the South Fork Shenandoah River) with historical industrial releases. Since then, however, state monitoring efforts have identified mercury contamination in a number of surface waters without readily identifiable sources.

Virginia expanded its mercury monitoring in 2002 based on an increasing scientific understanding of mercury's environmental chemistry and discoveries in other states (e.g., Florida, Maryland) of mercury pollution in water bodies without direct sources. The 2002 monitoring effort focused on rivers of the coastal plain, mostly to the east of I-95. As a result of this effort, Virginia found elevated mercury levels in some fish in the Blackwater River, the Great Dismal Swamp Canal, the Dragon Run Swamp, and the Piankatank River. Consistent with findings from Florida and elsewhere, these water bodies in Virginia possess characteristics favorable for the formation of the highly bio-accumulative form of mercury, methyl mercury. These characteristics include low dissolved oxygen, high organic matter, and low pH, and are most prevalent in "backwaters" of the southeastern portion of the state.

The primary source of mercury to these water bodies is suspected to be atmospheric deposition. There are currently three Mercury Deposition Network (MDN) sites located in Virginia, in Shenandoah National Park, Culpeper, and Harcum and data from these sites have contributed to the regional characterization of mercury transport and deposition throughout the state. Additional monitoring at the Harcum site in 2005 revealed that dry deposition of reactive gaseous (divalent) mercury along the Piankatank River (near the Chesapeake Bay) and in upstream areas is an important contributor to the high mercury levels observed in the water and fish in the area.

Global, regional, and local sources of air mercury emissions contribute to the deposition, and understanding these contributions is an important step toward identifying measures that will effectively reduce mercury deposition and environmental mercury levels.

Objectives

This study includes a detailed analysis of mercury emissions inventory data, as well as a comprehensive mercury deposition modeling analysis. Both the data analysis and modeling components are intended to examine and quantify the contribution of regional and local emissions sources to mercury deposition throughout the Commonwealth, and to provide information to support the further analysis of the impact of mercury deposition on the environment.

For each of the bodies of water listed as impaired by Virginia, the Clean Water Act calls for the calculation of a Total Maximum Daily Load (TMDL). TMDLs identify the pollutant reductions or limits that are needed in order to achieve water quality standards. TMDLs must also allocate the reductions to the different sources of pollution, including air sources. Thus another key objective of the data and modeling analyses is to provide information that will enable VDEQ to conduct TMDL studies.

Finally, the results of this study will also be used to support VDEQ's evaluation of potential measures needed to reduce mercury emissions in Virginia. Specifically, the data and modeling analysis studies will allow VDEQ to evaluate the effectiveness of selected control measures and support the development of management strategies for meeting water quality criteria and protecting human health.

On the project management side, our objectives are to develop and implement a sound program management plan that supports and ensures our ability to 1) deliver high quality technical services within the proposed schedule and budget, and 2) address any problems that arise during the course of the study in a prompt, responsible manner. Other requirements include several meetings, conference calls, and monthly written progress reports.

2. Scope of Work for Section A: Mercury Emissions Data Analysis

The emissions data analysis focuses on the review and refinement of the mercury emissions data from a variety of source categories, which include coal-fired utilities, medical waste incinerators, and municipal waste incinerators. The emissions data analysis also requires the reliable projection of these data to three future years, accounting for the requirements of the Virginia General Assembly Bill that limits participation by sources located in Virginia in the mercury emissions federal trading program. The reliability of the mercury deposition assessments, including the modeling, will depend significantly on the quality and completeness of the emission inventory data. Thus, a key objective of the emissions data analysis component of the study will be to assess and improve, as needed, the reliability of the mercury emissions data.

Section A of the Virginia Mercury Study consists of eight tasks, as follows.

Task 1: Air Point Source Mercury Emissions Inventory Review

In this task, we will acquire, review, and summarize mercury emissions estimates based on the information contained in the latest version of the National Emissions Inventory (NEI) and state-specific emissions data provided by Virginia DEQ. This task will focus on emissions for 2002, since the mercury deposition modeling will utilize emissions for a base year of 2002.

VDEQ recently solicited on the order of 75 specific sources for updated mercury emission estimates for 2002 and 2005. Our first task will be to review the information obtained from this survey. Of those sources that provided updated information, some sources prepared emissions estimates based on measurements (stack tests), while others based their estimates on standard process-based emission factors for various source types (e.g., AP-42). Still others may have estimated emissions using alternative methods.

For each facility for which we are provided information, we will conduct a thorough technical review of the emissions estimates, taking into account the important factors that affect mercury emissions such as process-type, boiler-type, fuel type, equipment-type, and stack parameters (e.g., flow rate, exit temperature, exit velocity, etc.). For each facility, we will assess the accuracy of the emission estimates and review all of the facility-specific information including location, stack parameters, hours of operation, maintenance schedules, and estimated diurnal operating profiles. We will also investigate whether any emission control or other equipment was installed or replaced between 2002 and 2005 and whether the facility is planning to change/update equipment in the near future. If new control or other equipment will be installed beyond 2005, this will be accounted for in the future-year emission estimates to be provided in Task 2 for 2010, 2015, and 2018.

As a starting point in our review and evaluation of sources outside Virginia, we will utilize existing mercury emissions estimates derived from version 3 of the National Emissions Inventory (NEI).

The analyses conducted in this task will be summarized in a draft technical memorandum. The memorandum will include data sources, methods, results, and estimates of uncertainty and limitations. The memorandum will be revised in accordance with comments from VDEQ and will then be incorporated into the mercury emissions data analysis report, to be prepared as part of Task 4.

Task 2: Mercury Emission Inventory Summary

In this task, we will utilize the information gathered and reviewed as part of Task 1 to update the Virginia mercury emissions inventory. We will also summarize the information/data to be used in the modeling analysis to be conducted in Section B of the study. Any changes to be made to update the Virginia point sources will be reviewed and approved by VDEQ staff prior to use in the modeling analysis. The evaluations and summaries will be provided by applicable source categories, such as electric generation, material processing, etc. The summary will include the outcome from the review of the methods used in estimating mercury emissions including stack tests, standard process/unit-based emission factors, or other methods. A comprehensive summary will be provided for the base-year (2002/2005) emission inventories, which will provide the bases for the future-year estimates.

In addition to the point source information reviewed as part of Task 1, we will also review and summarize all other anthropogenic and geogenic sources of mercury emissions. For this analysis, we will focus on the Mid-Atlantic states in depicting the spatial distribution of low-level and elevated sources potentially affecting Virginia.

In this task, we will also prepare future-year estimates of mercury emissions for point and non-point sources in Virginia for 2010, 2015, and 2018. These estimates will take into account the provisions of CAMR and HB1055 on Virginia sources.

The CAMR, promulgated on May 18, 2005, includes two mechanisms to reduce mercury emissions from electric power plants. First, it sets standards of performance for new and existing coal-fired power plants. Second, it establishes a two-phase, national cap-and-trade program. In the initial phase of the cap-and-trade program, the national mercury emissions will be capped at 38 tons and emissions reductions will occur as a “co-benefit” of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions under the Clean Air Interstate Rule (CAIR) issued on March 10, 2005. In the second phase, due in 2018, coal-fired power plants will be subject to a second cap, which will reduce emissions to 15 tons upon full implementation.

To participate in the cap-and-trade program, states must submit to EPA a State Implementation Plan revision that describes how the state will meet its mercury reduction budget. States may adopt a “model rule” or a rule(s) with comparable provisions. Legislation enacted by Virginia in April 2006 authorized the Air Pollution Control Board to adopt and submit to EPA the model rule. As described below, the Virginia legislation also provided authority for state-specific rules to further control mercury emissions from sources regulated under CAMR. These are summarized by the following amendments to the Code of Virginia:

- § 10.1-1328 C—This section directs the Air Pollution Control Board to adopt and submit to EPA the CAMR “model rule” for participation in the federal mercury cap-and-trade trading program. The rule will include a set-aside of mercury allowances for new sources not to exceed 5 percent of the total state budget during the first five years and 2 percent thereafter.
- § 10.1-1328 D—This section is a state-specific (i.e., that exceeds the requirements of the CAMR rule) rule. Its requirements are similar to the CAMR cap-and-trade program, but it applies to additional (smaller) sources and includes additional restrictions on compliance options.
- § 10.1-1328 E—This section directs the Air Pollution Control Board to adopt regulations governing mercury emissions that meet, but do not exceed, the requirements and implementation timetables for (i) any coke oven batteries for which the EPA has promulgated standards under § 112(d) of the

Clean Air Act, and (ii) facilities subject to review under § 112(k) of the Clean Air Act and that receive scrap metal from persons subject to § 46.2-635 of the Code of Virginia.

- § 10.1-1328 F—This section is a state-specific rule that prohibits electric generating facilities in nonattainment areas from meeting mercury compliance obligations by purchasing credits from other facilities. An exception applies when the facility owner can demonstrate compliance using allowances at another of its facilities within 200 kilometers of the Virginia boarder.

We will work with VDEQ in to translate these rules and provisions into emissions estimates and incorporate them into the future-year emission inventories, staging them as appropriate, for each future year. The future-year estimates will reflect the implementation, timing and effects of the CAIR and CAMR emission reduction provisions.

The work in this task will also include an analysis of expected emissions reductions, future-year trends for all source categories, and a comparison of Virginia emissions with neighboring states, regions, national, and global sources affecting Virginia.

The analyses conducted in this task will be summarized in a draft technical memorandum. The memorandum will include data sources, methods, results, and estimates of uncertainty and limitations. The draft memorandum will be revised based on comments from VDEQ and incorporated into the mercury emissions data analysis report, to be prepared as part of Task 4.

Task 3: Literature Review

In this task we will conduct a literature review of recent research into “atmospheric chemistry and reactivity, mercury deposition mechanisms, and physical and chemical characteristics of mercury.” We will also review reports addressing mercury emissions issues, deposition modeling, and modeling studies conducted to estimate global background values of mercury. The starting point for this task is the literature already compiled and organized by VDEQ.

We will summarize the findings of these studies in a draft technical memorandum, which will include a list of data sources, references, journals, and web sites found as part of the review. The draft memorandum will be revised based on comments from VDEQ and incorporated into the mercury emissions data analysis report, to be prepared as part of Task 4.

Task 4: Mercury Emissions Data Analysis Report

In this task, based on information prepared as part of Tasks 1-3, we will prepare a comprehensive draft mercury emissions data analysis report. The report will incorporate the memoranda prepared for each of these tasks and all comments received from VDEQ. The report will also include an Executive Summary.

Task 5: Data Archival and Transfer of Inventory Files

All of the data, data files, and software required to corroborate the results and findings of the study will be provided to VDEQ in an approved electronic format. We will utilize ftp methods for transfer of smaller files and portable disk drives for the transfer of larger files and/or the complete database.

Task 6: Quality Assurance Plan

We will prepare draft and final versions of a Quality Assurance Plan (QAP) that will address all aspects of the technical effort covering both Sections A (emission inventory review/analysis) and Section B (mercury deposition modeling). The QAP will include procedures for reviewing emission data, processing and use of air quality, meteorological, and emissions data, as well as the application of the modeling tools. The QAP will be prepared in accordance with EPA requirements governing QAP preparation. Its purpose will be to ensure that the emissions inventory and modeling study is scientifically sound and error free. The QAP will address:

- Data acquisition (sources and procedures).
- Data quality assurance and processing procedures.
- Stepwise checking of each analysis component (emission inventory review, data analysis and processing, modeling emission inventory preparation, model application, postprocessing of the model outputs, display, and analysis of the modeling results, and documentation).
- Internal and external review of all presentation materials and documentation.
- Communication and resolution of technical issues (in conjunction with VDEQ).

The QAP will be prepared so that it will guide our technical work, as well as the quality assurance of data and modeling results once they are delivered to VDEQ. We will assign a quality assurance officer to each project task. This will be an individual who has a comprehensive understanding of the task, but is not involved in the detailed technical work for that task.

A draft QAP will be prepared and submitted to VDEQ for review at the beginning of the project. A revised QAP will be prepared prior to the conclusion of the project, and finalized based on comments.

Task 7: Project Management

Jay Haney will serve as the ICF project manager. He will be responsible for the:

- Day-to-day management of all technical tasks.
- Technically sound and efficient completion of each task and the entire project.
- Communication with the VDEQ, including the exchange of ideas and information and prompt responses to questions from VDEQ.
- Development and refinement of the project scope of work in cooperation with VDEQ and other project participants
- Conformity with the modeling protocol and implementation of the QAP
- Resolution of any technical and project-management-related issues.
- Quality and timeliness of all project deliverables.

As part of this task, Mr. Haney and other scientists from ICF will participate in biweekly (or as needed) conference calls and up to four one-day project meetings covering the emissions data analysis and modeling work.

The work plan (this document) will be revised as needed during the course of the project to reflect progress to date and to ensure a successful completion of the project.

Each month, progress will be evaluated against this work plan and summarized in a written status report to VDEQ. The status reports will provide a detailed discussion of work accomplished during the report period, results achieved during the reporting period, problems encountered and how they were resolved, and planned activities for the next two months. The status report will also include a summary of expenditures for the period and cumulative expenditures for the project.

Task 8: Other Tasks Not Assigned

Under this task, we will respond to any additional requests that VDEQ may have for work related to the review of the mercury emission inventory. We will be pleased to provide a scope of work and cost estimate for any additional tasks that arise during the course of the study.

3. Scope of Work for Section B: Mercury Deposition Modeling

The modeling analysis includes the development of a conceptual description of mercury deposition, which will improve the overall understanding of the mercury problem and the relationships between meteorology and mercury deposition. The modeling results will provide a basis for quantifying the contribution of emissions sources to mercury deposition and examining the fate of mercury emissions from selected sources. For environmental planning purposes, the modeling will be used to examine the effectiveness of control measures in reducing mercury concentrations in contaminated bodies of water and improving or maintaining water quality within the designated areas of interest in Virginia. By quantifying deposition, the modeling results will also provide a link between the analysis of mercury emissions and the assessment of the impacts of airborne mercury on fish tissue and human health.

Section B of the Virginia Mercury Study consists of ten tasks, as follows.

Task 1: Conceptual Model

A “conceptual model” or “conceptual description” will be developed to characterize the key mercury deposition issues for Virginia in terms of geographic extent, severity, meteorological influences, and emissions sources. The key questions to be addressed in the conceptual description are listed in the RFP and include:

1. What are the specific meteorological parameters that influence mercury deposition in Virginia in the order of importance?
2. Is the mercury deposition problem primarily a local one, or are regional, national, and global factors important?
3. Are there any characteristic spatial patterns of mercury deposition?
4. Are there discernable trends in mercury deposition and are they accompanied by recent changes in emissions?
5. What past mercury modeling has been performed for Virginia and to what extent are the results consistent with the present study?

We will add the following questions to this list:

6. Are there any characteristic temporal (seasonal) patterns of mercury deposition?
7. To what extent are the trends in mercury deposition (from Question 4 above) associated with trends in meteorological conditions?
8. What do the results of recent mercury modeling of Virginia indicate regarding the relative importance of wet versus dry deposition, and regarding the species distribution of the deposition?

Our approach to the development of a conceptual description for mercury deposition will include analysis of mercury deposition, meteorological, and emissions data as well as examination of prior modeling results, with emphasis on the most recent national-scale mercury modeling analysis that we recently completed for the EPA Office of Water (OW).

As a starting point in this analysis, we will assemble available mercury deposition data for sites in Virginia and several nearby and surrounding states (North Carolina, Tennessee, Kentucky, West Virginia, Pennsylvania, Maryland, Delaware, and New Jersey) for the period 1996-2006.

This will include data from the Mercury Deposition Network (MDN) available from the National Acid Deposition Program (NADP) as well as any special studies that have been conducted. There are currently three MDN sites located in Virginia, in Shenandoah National Park, Culpeper, and Harcum. The period of record for the MDN data is late 2002 to present for the first two sites and approximately 2005 to present for the Harcum site. Each measurement of wet deposition represents a seven-day period. We will also assemble available meteorological data for surface and upper-air meteorological monitoring sites collocated with or near to the Virginia mercury monitoring sites, and will calculate meteorological summary parameters that describe the conditions over each approximate seven-day period represented by the mercury observations. The summary parameters will include, for example, total rainfall, number of days with rainfall, maximum 24-hr rainfall, average daily maximum and minimum temperatures, average relative humidity, average wind speeds, frequency of occurrence of wind directions, and a recirculation index. We will prepare graphical and tabular summaries that will provide an overview of the data and highlight key features/components of the datasets, such as the regional (site-to-site) differences in the seasonal and annual deposition values, corresponding seasonal and annual rainfall totals, and year-to-year variations in the deposition amounts and meteorological conditions.

As part of this task, we will use the Classification and Regression Tree (CART) analysis technique to probe the relationships between mercury deposition and meteorology. CART analysis (Brieman et al., 1984; Steinburg and Colla, 1997) is a statistical analysis tool that can be used to identify relationships between mercury deposition and meteorological parameters. CART accomplishes this through the development of a classification tree, in which the branches of the tree represent different types of meteorological conditions that lead to different values of mercury deposition. In constructing the classification tree, CART also determines the relative importance of the meteorological parameters to deposition. In addition, the frequency of occurrence of the conditions associated with each classification group (representing a deposition amount) can be determined.

In the context of this study, the CART results will be used to refine the conceptual description for mercury deposition for each monitoring site. CART will provide information on the different combinations of meteorological parameters that lead to different amounts of mercury deposition, the relative importance of the various meteorological parameters, and the frequency of occurrence of the conditions associated with each deposition classification group.

The CART results will also be used to examine and distinguish between the effects of meteorology and the effects of emissions changes on observed changes in mercury deposition. Year-to-year variations in observed mercury deposition amounts will be compared with year-to-year variations in the meteorological conditions (and specifically the frequency of occurrence of the different types of meteorological conditions affecting mercury deposition). We will account for the effects of meteorological variations before attempting to reconcile any trends in observed deposition amounts to changes in emissions.

We will also use existing modeling results to further develop our understanding of the characteristics of mercury deposition in Virginia. The ICF air quality modeling group has recently completed a modeling study for the EPA OW involving the analysis and tracking of airborne mercury emissions (Myers et al., 2006). We have used the REMSAD modeling system along with the PPTM approach to tag and track emissions from approximately 300 sources throughout the contiguous 48 U.S. states and have examined the contribution of these emissions to mercury deposition in each state. We will conduct some additional analysis of the results from the EPA-sponsored study to obtain preliminary model-based information on the spatial distribution of mercury deposition, the relative importance of wet versus dry deposition at the monitoring sites and within selected areas of interest in Virginia, the speciation characteristics of the simulated deposition, and the sources contribution to the simulated deposition.

The conceptual model will be documented in a project report for review and approval by VDEQ prior to conducting the modeling. The conceptual model will be used to guide 1) the selection of an appropriate modeling system for this study, 2) the selection of an appropriate simulation period and model input databases, and 3) the evaluation and interpretation of the modeling results.

Task 2: Modeling Protocol

In this task, we will prepare a modeling protocol that will provide a basis for all participants to review and comment on all aspects of the modeling analysis including the modeling tools and databases, modeling domain and simulation period, modeling procedures, quality assurance procedures, schedule, and communication structures. The protocol will be used to guide the progress of the modeling analysis and any decisions that need to be made as the work is progressing. Although there are no current guidelines for mercury modeling, we will design the modeling protocol and the modeling practices to be consistent, wherever applicable, with current EPA guidelines for ozone and particulate modeling (EPA, 2006).

An initial version of the protocol document will be developed for review and approval by VDEQ prior to conducting the modeling. It will be revised to document decisions made during the project, and finalized for inclusion in the final report.

Task 3: Model Sensitivity Analysis

Mercury is a complex pollutant to simulate, in part because transport of mercury in the atmosphere involves many different scales. At the global scale, mercury is known to reside in the atmosphere for long periods of time and is transported around the globe in its elemental form. At the regional and local scales, divalent forms of mercury emitted from sources can have impacts downwind, in some cases immediately downwind, of those sources. Thus modeling of mercury deposition must account for the global, regional, and local components.

The chemistry of mercury formation also contributes to the complexity required of mercury deposition modeling. Mercury exists in the atmosphere in an elemental form and in a number of different compounds. These various forms of mercury react with other species in the atmosphere resulting in a cycling of the airborne mercury among the different forms.

Our approach for mercury deposition modeling for Virginia accounts for the different scales and chemical interactions through the combined use of a state-of-the-science regional modeling system with source-contribution-assessment capabilities, specification of boundary conditions for the regional model based on global modeling, and a Gaussian model for the detailed assessment of local contributions.

This task will focus on configuring the modeling system and ensuring the suitability of the selected databases for the application for Virginia. In the remainder of this task description, we address modeling system and database selection and the use of model sensitivity analysis to establish the model configuration and application procedures.

Modeling System and Database Selection

Different types of models are designed for different scales and purposes. Gaussian models are able to resolve impacts near a source, but are not the best choice for longer range transport and for cases involving complex chemical reactions. Grid models such as CMAQ and REMSAD are well suited to treating the influences of many emissions sources and incorporate complex chemical mechanisms. However, effects smaller than the size of a grid cell may not be resolved by these models. Therefore, to account for the different scales as well as the important chemical interactions, we will use a two-tiered hybrid approach to the modeling.

At the regional scale, we will apply the latest version (version 4.6) of the Community Multiscale Air Quality (CMAQ) modeling system. The CMAQ model is a state-of-the-science, regional air quality modeling system that is designed to simulate the physical and chemical processes that govern the formation, transport, and deposition of gaseous and particulate species in the atmosphere. The CMAQ modeling system supports the detailed simulation of mercury (Hg), including the emission, chemical transformation, transport, and wet and dry deposition of elemental, divalent, and particulate forms of mercury.

We have enhanced the CMAQ modeling system recently to include the Particle and Precursor Tagging Methodology (PPTM) for mercury (Douglas et al., 2006). This methodology is designed to provide detailed, quantitative information about the contribution of selected sources, source categories, and/or source regions to simulated mercury concentrations and (wet and dry) deposition. Mercury emissions from selected sources, source categories, or source regions are (numerically) tagged and then tracked throughout a simulation, and the contribution from each tag to the resulting simulated concentration or deposition for any given location can be quantified. By tracking the emissions from selected sources or source locations, the methodology also provides information on the fate of the emissions from these sources.

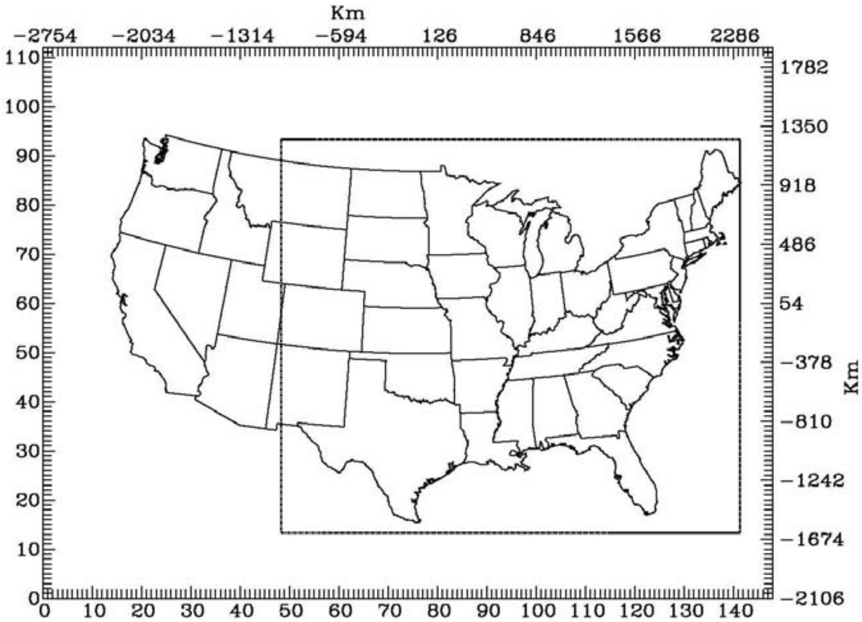
To support the application of CMAQ, we currently have multiple sets of global model simulation results that can be used to provide boundary concentrations for a national- (or continental-) scale simulation of mercury. These are discussed in more detail in the next subsection.

At the local scale, we will apply the most recent version of the EPA Gaussian model AERMOD. The AERMOD modeling will be performed for selected point sources in the Virginia emissions inventory (these will be selected based on the results of the emissions data analysis and may include up to 100 sources). We propose to use AERMOD to screen the mercury emissions sources and to determine which have the potential to impact areas outside the vicinity of the source. This screening step would provide the maximum expected impact from each source based on the directly emitted divalent forms of mercury. We will also use AERMOD (in Task 5) to simulate the effects of local emission changes for selected areas and sources.

This combination of modeling tools will allow us to address the variety of factors influencing mercury deposition in Virginia.

In order to apply the modeling tools, we will also need to obtain or prepare input databases to represent the emissions, meteorology, and geographic characteristics of the selected modeling domain and simulation period. The CMAQ modeling domain is illustrated in Figure 3-1. This domain includes the contiguous 48 states and supports 12-km horizontal grid resolution over Virginia.

Figure 3-1. CMAQ 36- and 12-km Nested-Grid Modeling Domain.



We will use the meteorological inputs used by EPA for the CAMR modeling, and recently updated to 12-km resolution. The meteorological inputs were generated using the Fifth Generation Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesocale Model (MM5). These meteorological inputs are for the year 2001. Corresponding meteorological inputs for AERMOD for 2001 will be developed using observed data.

Similar meteorological inputs are also available (from EPA) for 2002. However, the summer of 2002 was characterized by lower than normal rainfall amounts in Virginia and surrounding states. Since summer can be an important time for mercury wet deposition, 2002 is not a good meteorological base year for the modeling exercise. We may conduct sensitivity testing with the 2002 meteorological inputs.

For the emissions inputs, we propose to use the latest version (version 3) of the 2002 National Emissions Inventory (NEI). Currently this inventory does not include mercury emissions for motor vehicle or non-road sources, but these are expected to be available in April 2007. We will incorporate the motor vehicle and non-road emissions when they become available. We will update this inventory with any new information obtained as part of the mercury emissions inventory review, discussed under Section A of the work plan. We will also review, and incorporate as appropriate, other updates for surrounding states that we received as part of our work for the EPA OW.

We will prepare the model-ready emissions for CMAQ using the SMOKE emissions processing program and will apply our standard quality assurance procedures to the emissions processing.

Sensitivity Simulations

To a large extent, model configuration for CMAQ will have been determined by the selection of the meteorological databases. Consequently, sensitivity simulations geared at model configuration will focus mainly on the application of AERMOD. We will design a series of tests to determine which of the parameter settings are best suited for mercury deposition and we will explore how to maximize consistency between the AERMOD and CMAQ models. Final recommendations on the configuration of both modeling systems will be provided to VDEQ for review and approval.

Following the establishment of the modeling platform, we will identify potential weaknesses in the model input fields and design and conduct sensitivity simulations to examine the effects of these weaknesses or uncertainties. For example, we may examine the sensitivity of the CMAQ simulation results to the different estimates of boundary concentrations that are currently available. We may also examine the potential for changes in speciation in the boundary conditions to affect the simulation results.

As noted earlier, we may also explore the sensitivity of the modeling results to the selection of the simulation period, by substituting the 2002 meteorological inputs.

The understanding of the atmospheric chemistry of mercury is still evolving. Therefore, if the literature search from Task A-3 reveals new developments in the formulation of the mercury chemistry, we will consider sensitivity simulations to investigate the potential effects of new reactions, speciation, deposition rates, or other factors affecting the estimation of mercury deposition.

Based on the results of the above studies, we will recommend a final model configuration. Any suggestions for changes to the inputs will also be provided.

The result of this task will be a draft technical summary of the modeling platform selection and model sensitivity analysis. A final version of this document will incorporate/address comments from VDEQ and will be incorporated into the modeling protocol.

Task 4: Model Performance Evaluation

In this task, we will use available data and some data analysis techniques to evaluate model performance for mercury deposition.

Data Availability

Mercury wet deposition data for Virginia are available for two Mercury Deposition Network (MDN) monitoring sites, Shenandoah National Park and Culpeper, beginning in October and November 2002, respectively. Additional data are also available for the Harcum site (in coastal Virginia) beginning in December 2004.

Mercury deposition data are also available for several surrounding states, within and adjacent to the Mid-Atlantic region. The period of record for these sites varies, and there are several sites in Pennsylvania, North Carolina, and South Carolina that have data for 2001. Sites in Arendtsville, Pennsylvania, Pettigrew State Park, North Carolina, and Waccamaw State Park, North Carolina are likely most representative, based on proximity and/or similar geographical features, to the areas of interest in Virginia. In particular, Pettigrew State Park, near the Albemarle Sound, may be representative of coastal Virginia.

These data will be obtained and processed in Task 1, for the period 1996-2006, in accordance with their availability. In addition, we have already obtained and worked with data for 2001 for all sites in the U.S. We will use all available observations for the model domain and region for 2001 for the direct calculation of model performance statistics. We will also use the data for 2003-2005 for sites in Virginia and throughout region to estimate deposition for 2001 at the Virginia monitoring sites. The estimated deposition values will then be used to further evaluate model performance for sites in Virginia.

Estimating Deposition for 2001 for the Virginia Monitoring Sites

We will use the results from the CART analysis conducted in Task 1 to estimate deposition for 2001 for the Virginia monitoring sites. Specifically, we will classify each seven day period in 2001 according to the observed meteorological conditions and determine the corresponding CART-based classification group. We will assign the average mercury deposition for the grouping (the average over all other periods in the classification group) to the 2001 weekly period. We will do this for each period for the entire year of 2001 and then use the weekly mercury deposition values to estimate seasonal and annual deposition amounts. The key assumption here is that observed mercury deposition for the later years can be used to estimate deposition for 2001 under similar meteorological conditions. Applying this assumption on a weekly basis allows us to account for the variable effects of meteorology throughout the year. We have used a similar approach for the EPA OW, in order to estimate annual mercury deposition for a ten-year period (Douglas et al., 2003). EPA then used these values for water quality modeling and estimating fish tissue concentrations.

In order to confirm the reasonableness of these results, we will also apply this same method for additional sites with longer term records: Arendtsville, Pettigrew State Park and possibly others. Ratios in the annual average deposition (for example, 2003/2001) for the sites will be examined and compared with those for the Virginia sites using the estimated data to ensure that the CART-derived estimated values are reasonable.

Assessment of Model Performance

In this section, we present our approach to model performance evaluation for both the CMAQ and AERMOD models. Following EPA guidance for evaluating model performance, we will examine 1) whether each model is able to replicate observed (and estimated) mercury deposition data, and 2) whether the response of the model to changes in mercury emissions is reasonable.

For the CMAQ model, we will compare the simulated total wet deposition of mercury with actual and estimated data for the MDN monitoring sites. We will compare simulated and observed wet deposition for each site and the average over all sites within 1) the full domain, 2) each CMAQ grid, 3) the mid-Atlantic region, and 4) Virginia.

A variety of statistical measures will be used to quantify model performance. These will include

- Mean observed deposition = $1/N \sum O_l$
- Mean simulated deposition = $1/N \sum S_l$
- Normalized bias (expressed as percent) = $100 \cdot 1/N \sum (S_l - O_l)/ O_l$
- Normalized gross error (expressed as percent) = $100 \cdot 1/N \sum |S_l - O_l|/ O_l$
- Fractional bias (expressed as percent) = $200 \cdot 1/N \sum (S_l - O_l)/ (S_l + O_l)$
- Fractional error (expressed as percent) = $200 \cdot 1/N \sum |S_l - O_l|/ (S_l + O_l)$
- Mean residual = $1/N \sum (S_l - O_l)$
- Mean unsigned error = $1/N \sum |S_l - O_l|$

- Coefficient of determination (R^2) =
$(\sum S_l O_l - \sum S_l \sum O_l/N)^2 / [(\sum O_l^2 - (\sum O_l)^2/N) \cdot (\sum S_l^2 - (\sum S_l)^2/N)]$

Where S is the simulated concentration, O is the observed concentration, and N is the number of simulation-observation pairs used in the calculation. Statistical measures will be calculated on a seasonal and annual basis.

Plots and graphics will also be used to assess the reasonableness of the results. Spatial plots of the simulated and observed values will be used to qualitatively assess the ability of the model to emulate the spatial deposition patterns. Monthly time-series plots comparing these same values at the monitoring sites will be used to determine whether the timing and magnitude of the simulated values matches the observations. Scatter plots will also be used to graphically compare the simulated and observed deposition values.

As part of the model performance evaluation, we will examine the response of the model for the sensitivity simulations conducted in Task 3. For example, we will ensure that the model responds in a reasonable way (based on our current knowledge of mercury chemistry and transport) to changes in the boundary conditions and changes in the speciation profiles of the emissions and /or boundary conditions. We will use PPTM as a probing tool and examine the PPTM results from Task 6 to verify that the contributions from selected emission sources are commensurate with the locations and emissions of the sources as well as the prescribed meteorological conditions.

For AERMOD, we will conduct a limited performance evaluation to assess whether the model is able to simulate the deposition distributions and maximum values represented by the observed and estimated data. As for CMAQ, we will examine the response of the model for the sensitivity simulations conducted in Task 3 to ensure that the model responds in a reasonable way (based on our current knowledge of near-source mercury deposition) to changes in the meteorological and emissions inputs.

Model Performance Goals

In keeping with current EPA guidance on model performance evaluation for other pollutants, we will use a “weight-of-evidence” approach to determine whether model performance for both CMAQ and AERMOD is good enough for use in future-year modeling and control measure assessment. For CMAQ, this will be based on the statistical performance measures, the response of the model to changes in the inputs, and the reasonable of the PPTM contribution results. For AERMOD, this will be based on the comparison of simulated and estimated data—particularly the distribution and maximum values. We will also compare the CMAQ and AERMOD results to assure that the simulated local contributions from AERMOD bound the CMAQ results, as they are more likely to represent the maximum impact from directly emitted divalent forms of mercury from a source.

The model performance evaluation task will be documented in a draft technical report. A final version of this document will incorporate/address comments from VDEQ and will be incorporated into the full mercury deposition modeling report developed under Task 6.

Task 5: Modeling Simulations

In this task we will use both the CMAQ and AERMOD models to examine the contributions of a variety of sources to mercury deposition to Virginia’s “impaired” water bodies.

Baseline Modeling

As a first step in the modeling we will conduct several simulations using the baseline 2002 emissions inventory. These simulations are designed to assess the contributions of various source sectors to mercury deposition to water bodies in Virginia. We will use CMAQ to simulate each of these scenarios.

The first scenario will examine and quantify the contributions from mercury air emissions sources in 1) Virginia, 2) the mid-Atlantic region (or selected neighboring states), 3) all other U.S. states, and 4) Canada and Mexico, as well as the contribution from 5) global emissions sources. As noted earlier, we will use CMAQ version 4.6 with PPTM. We will assign tags to each of the five regions/categories listed above. An initial/boundary condition tag will represent the global impact on deposition. This set of tags provides estimates of Virginia, regional, national, and global impacts on deposition for any location (grid cell or group of grid cells) within the state or the modeling domain.

The second scenario will quantify the contributions from Electric Generating Unit (EGU) and non-EGU facilities in Virginia. We will tag 1) all of Virginia's EGU sources and separately 2) all of the non-EGU sources in the state. The results will allow VDEQ to quantify and compare the contributions from these two source sectors to mercury deposition for any location (grid cell or group of grid cells) within the state or the modeling domain.

The third CMAQ scenario will examine the contributions from other sources that, based on the original AERMOD screening test in Task 3, were identified to have potential impacts on mercury deposition outside of their immediate vicinity (potential non-local or regional impacts). This scenario may involve more than one CMAQ simulation, since currently each CMAQ PPTM simulation can include up to seven tags. These results will allow VDEQ to quantify the contributions from facilities with a potential regional influence, extending across a large portion of the state.

Finally, to conclude the baseline modeling, we will apply AERMOD to those sources that were identified in Task 3 to have significant local impacts on one or more of Virginia's "impaired" water bodies. These results will allow VDEQ to quantify the contributions from individual sources with a potentially significant local impact.

Any changes to the inputs or emissions incorporated as a result of the diagnostic and sensitivity testing and performance evaluation (Tasks 3 and 4) will be reflected in the baseline application of CMAQ and AERMOD. We will provide the baseline emissions to VDEQ for review and approval prior to conducting the baseline modeling.

The CMAQ PPTM results will be displayed in a variety of graphical and tabular formats. Spatial plots depicting the contributions from each of the tagged sources or source categories will be prepared.

We will also work with VDEQ to assemble a list of water bodies and hydrologic zones and will conduct a detailed analysis of the results for these areas. Specifically, we will prepare tabular summaries of the results, including total deposition, total wet and dry deposition, deposition by species, and contribution by source and/or source category for each of the areas of interest. In addition to the tabular summaries, we will prepare graphical displays of the results.

The AERMOD results of the local contributions will be summarized using tables as well as pie and bar charts.

Future-Year Emission Inventory Preparation

To support the future year modeling, we will prepare model-ready future year emission inventories. These will be prepared for 2010, 2015, and 2018 using the projected emissions from the emissions data analysis component of the project. We will provide the project future-year emissions, including growth and control assumptions, to VDEQ for review and approval prior to conducting the future year modeling.

Emissions for AERMOD will be directly obtained from these estimates. For CMAQ, the model-ready emissions will be processed using the SMOKE emissions processing program. We will apply our standard quality assurance procedures to the emissions processing.

The future-year emissions will reflect the CAMR for all states. For Virginia, the future year emissions will include the requirements of the state-specific rules that are being developed in conjunction with the Virginia General Assembly (HB1055). This is discussed in more detail as part of Task 2 of the emissions data analysis.

We will work with DEQ to translate these rules and provisions into emissions estimates and incorporate them into the future-year emission inventories, staging them as appropriate, for each future year.

Future-Year Modeling

The future-year modeling exercises will include the same CMAQ PPTM and AERMOD runs as the baseline simulations. For each future year, we will examine the simulated change in mercury deposition, overall and from each tagged or modeled source or source category. The use of the PPTM methodology will enable us to attribute the future-year reductions in mercury deposition for each area of interest to the specific tagged sources or source categories. Graphical and tabular summaries of the results will be prepared.

Our analysis of the results will focus on the effectiveness of the various measures and emissions changes in reducing future-year mercury deposition. Given the uncertainties associated with mercury deposition modeling, we will emphasize the relative changes in deposition associated with the emissions changes for each source and source category in our analysis of the results.

Task 6: Mercury Deposition Modeling Report

This task will cover the preparation of the documentation for the study. The report will summarize the data, methods, and results of the study. A portion of the report will be devoted to a discussion of the uncertainties and limitations associated with the methods and the modeling results, based on known data limitations, input preparation assumptions, model formulation and modeling assumptions, model performance, and differences between the CMAQ and AERMOD results. As noted earlier, this report will include revised, updated versions of draft report sections prepared as part of Tasks 3 and 4.

The report will contain an executive summary, technical details of all aspects of the modeling analysis, a discussion of the uncertainties and limitations of the results, and information on how to access and utilize the modeling datasets. The report will contain a variety of graphical summaries of the inputs and results including, as required in the RFP, maps illustrating simulated mercury deposition, stationary source emissions, and fish consumption advisory information for each of the future-year analyses.

We will develop and submit an outline for the report for review by VDEQ prior to preparation of the draft report. Draft and final versions of the report will be prepared. The final report will be incorporate and address comments by VDEQ and will be completed within four weeks of receipt of the comments.

Task 7: Data Archival and Transfer of Inventory Files

All of the data, data files, and software required to corroborate the results and findings of the study will be provided to VDEQ in an approved electronic format. We will utilize ftp methods for transfer of smaller files and will use portable disk drives for the transfer of larger files and/or the complete database.

Task 8: Quality Assurance Plan

The QAP covering both the emissions inventory review and deposition modeling work will be prepared as one document as part of Section A, Task 6.

Task 9: Project Management

Jay Haney will serve as the ICF project manager. He will be responsible for the management of all technical tasks, communication with the VDEQ, refinement of the project scope of work in cooperation with VDEQ and other project participants, conformity with the modeling protocol and implementation of the QAP, resolution of any technical and project-management-related issues, and ensuring the quality and timeliness of all project deliverables.

As part of this task, Mr. Haney and other scientists from ICF will participate in biweekly (or as needed) conference calls and up to four one-day project meetings covering the emissions data analysis and modeling work.

Each month progress will be evaluated against this work plan and summarized in a written status report to VDEQ. The status reports will provide a detailed discussion of work accomplished during the report period, results achieved during the reporting period, problems encountered and how they were resolved, and planned activities for the next two months. The status report will also include a summary of expenditures for the period and cumulative expenditures for the project.

Task 10: Other Tasks Not Assigned

ICF will be pleased to provide a scope of work and cost estimate for any additional tasks that arise during the course of the study.

4. Overview of the Project Team

In this section, we briefly outline the roles and responsibilities of the key project participants.

- For this effort, **Jay Haney** will serve as Project Manager. He will be the principal point of contact for VDEQ and will ensure that adequate corporate and administrative resources are available to accomplish the technical objectives and meet the proposed schedule and budget.
- **Sharon Douglas** will serve as Technical Coordinator. Ms. Douglas will work closely with Mr. Haney to: 1) develop the modeling recommendations and protocol, 2) develop the approach for the mercury data analysis, 3) conduct the modeling and technical analyses, 4) communicate ongoing technical information to the VDEQ project participants by participating in conference calls and status meetings, and 5) prepare the draft and final reports. She will have day-to-day responsibilities to coordinate the technical work conducted by all project participants and will work closely with Mr. Haney to ensure that the work is completed on schedule and within budget.
- **Tom Myers** will lead the mercury modeling application, evaluation, and sensitivity analysis. He will lead the set up and application of CMAQ with PPTM, as well as the processing and analysis of the CMAQ and mercury tagging results. He will assist in evaluating both air quality models, and will apply his understanding of the physical and chemical processes affecting mercury to the analysis of the results.
- **Belle Hudischewskyj** will be responsible for acquiring, reviewing, and coordinating all handling of the air quality and meteorological data required for this study. She will participate in the CART analysis and will prepare the meteorological inputs for application of the Gaussian model.
- **David Burch** will participate in the mercury emissions inventory data evaluation and literature search.
- **YiHua Wei** will participate in the emissions evaluation and lead the emissions inventory preparation work and the AERMOD application for the mercury deposition modeling task.
- **Boddu Venkatesh** will participate in identifying/reviewing emissions inventory information provided by ICF's IPM energy demand model.

Additional ICF personnel will participate in the study and provide support to the key personnel, as appropriate.

- **Tim Lavallee** from LPES, Inc. will assist ICF with the mercury emissions data analysis task, and specifically the review and analysis of the point source mercury emissions inventory information compiled by VDEQ for industrial point sources for 2002 and 2005.
- **Diane Shotynski** of Thruput will participate in the mercury emissions data analysis, where she will assist in the literature search as well as the review and analysis of the point source mercury emissions inventory information.

5. Schedule and Deliverables

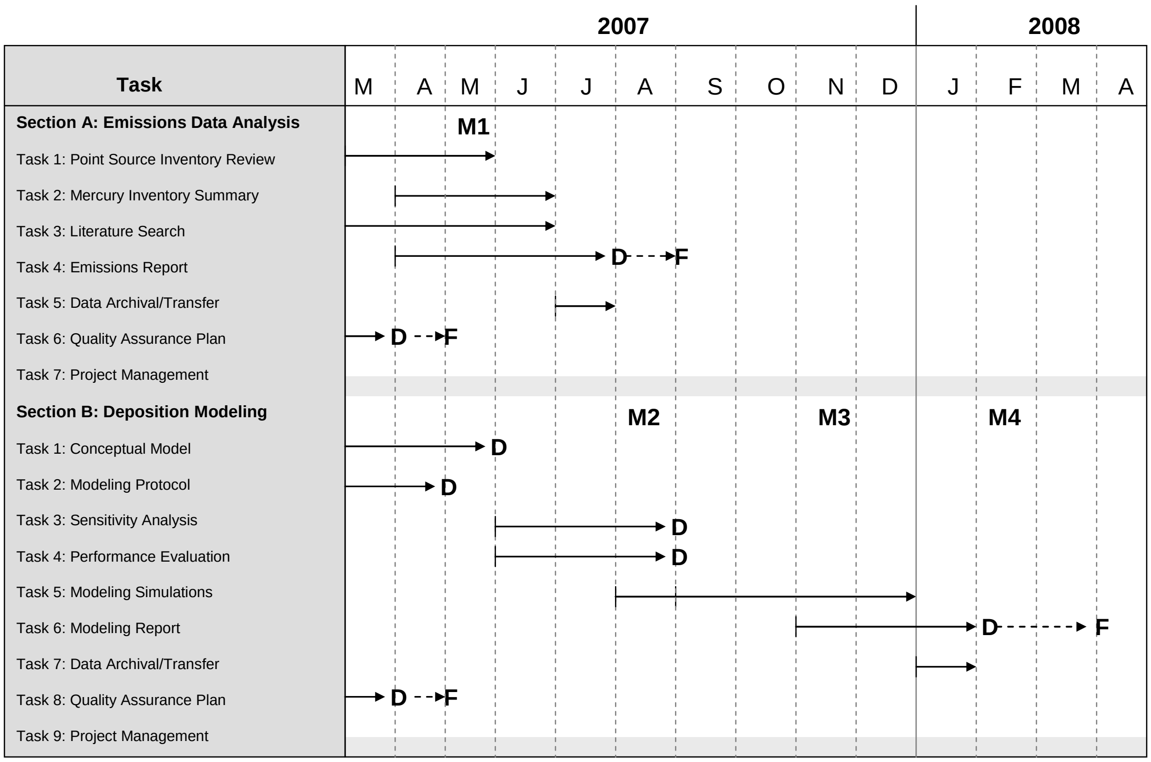
In this section, we present a schedule and list of deliverables for the work outlined above for the Emissions Inventory Data Analysis (Section A) and Mercury Deposition Modeling (Section B).

Schedule

Figure 5-1 presents the schedule for conducting the technical tasks.

Figure 5-1. Proposed Schedule for Completing Parts A and B of the Virginia Mercury Study

(shading represents ongoing activity).



Key:
M1 – **M4** = Project meetings
D = Draft
F = Final

Milestones and Deliverables

Milestones and deliverables for work conducted under Parts A and B of the Virginia Mercury Study are listed and estimated completion dates are provided in the remainder of this section.

Part A—Mercury Emissions Data Analysis

Milestone/Deliverable	Expected Completion Date
Task 1: Point Source Inventory Review	
Acquire VA point-source emissions data from VDEQ	2/21/2007
Select national-scale inventory	3/15/2007
Review & summarize emissions data	4/30/2007
Task 2: Mercury Inventory Summary	
Update VA emissions	5/15/2007
Summarize base-year emissions for modeling	5/15/2007
Prepare future-year emission estimates	6/15/2007
Summarize reductions/compare with other states	6/15/2007
Prepare draft memorandum	6/30/2007
Task 3: Literature Search	
Conduct literature review	6/15/2007
Prepare draft memorandum	6/15/2007
Task 4: Emissions Report	
Prepare draft emissions data analysis report	7/15/2007
Prepare final emissions data analysis report	2 weeks following VDEQ review
Task 5: Data Archival/Transfer	
Transfer inventory files to VDEQ	7/31/2007
Task 6: Quality Assurance Plan	
Prepare draft quality assurance plan	3/31/2007
Prepare final quality assurance plan	2 weeks following VDEQ review
Task 7: Project Management	
Prepare monthly progress reports	Monthly
Participate in bi-weekly conference calls	Bi-weekly, as scheduled
Conduct 1st technical meeting	~ 5/15/2007

Part B—Mercury Deposition Modeling

Milestone/Deliverable	Expected Completion Date
Task 1: Conceptual Model	
Assemble & review data	4/15/2007
CART analysis	5/15/2007
Review existing modeling results	5/15/2007
Develop/document conceptual model	5/31/2007
Task 2: Modeling Protocol	
Address/finalize key decisions	3/15/2007
Prepare draft modeling protocol	4/15/2007
Task 3: Sensitivity Analysis	
Set up CMAQ modeling platform & databases	6/15/2007
Set up AERMOD modeling platform & databases	6/15/2007
CMAQ sensitivity simulations	8/15/2007
AERMOD sensitivity analysis	8/15/2007
Prepare draft report on sensitivity analysis	8/31/2007
Task 4: Performance Evaluation	
Prepare estimated data	6/15/2007
Evaluate model performance	8/15/2007
Prepare draft report on model performance	8/31/2007
Task 5: Modeling Simulations	
Prepare future-year emission inventories	9/15/2007
Conduct baseline CMAQ PPTM simulations	10/31/2007
Conduct baseline AERMOD modeling	10/31/2007
Summarize contribution results	10/31/2007
Conduct future-year CMAQ PPTM simulations	12/15/2007
Conduct future-year AERMOD modeling	12/15/2007
Display & analyze modeling results	12/31/2007
Task 6: Modeling Report	
Prepare draft mercury deposition modeling report	1/31/2008
Prepare final mercury deposition modeling report	2 weeks following VDEQ review
Task 7: Data Archival/Transfer	
Transfer modeling files to VDEQ	1/31/2008
Task 8: Quality Assurance Plan	
Prepare draft quality assurance plan	3/31/2007
Prepare final quality assurance plan	2 weeks following VDEQ review
Task 9: Project Management	
Prepare monthly progress reports	Monthly
Participate in bi-weekly conference calls	Bi-weekly, as scheduled
Conduct 2nd technical meeting	~ 8/15/2007
Conduct 3rd technical meeting	~ 11/15/2007
Conduct 4th technical meeting	~ 2/15/2008

6. References

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